National Aeronautics and Space Administration

Transport during the January/February 2006 Stratospheric Major Warming from Aura MLS and ACE-FTS data

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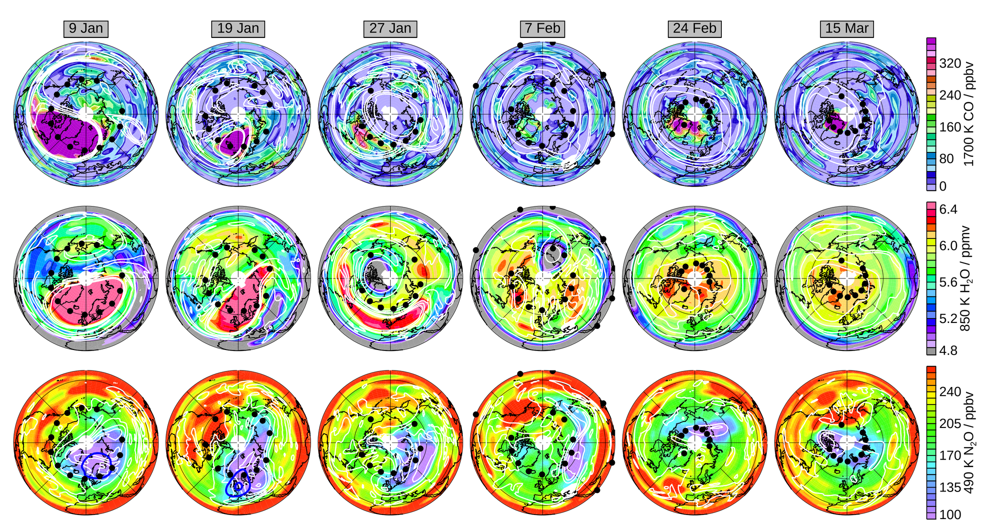
1 The 2006 Major Stratospheric Sudden Warming: Introduction and Synoptic Overview



A very strong "major" stratospheric sudden warming (SSW) began in January 2006. We have an unprecedented wealth of long-lived trace gas data covering the stratosphere and lower mesosphere during the January/February 2006 major SSW:

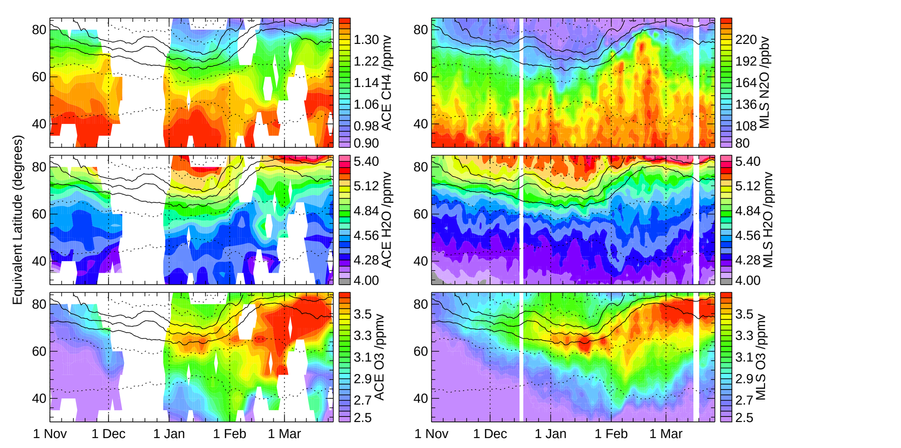
- No major warmings during the UARS mission
- Latest previous major warming in January 2004 only very sparsely covered by early ACE data, and before Aura launch with EOS MLS
- The preceding figure shows Aura MLS tracers at 1700 K (upper stratosphere (US), CO), 850 K (middle stratosphere (MS), H_2O) and 490 K (lower stratosphere (LS), N_2O) during the SSW; white overlays are PV contours. Black dots show the ACE-FTS observation locations

- Nearly complete break down of vortex throughout stratosphere
- US vortex reformed quickly to become unusually strong by mid-February
- MS vortex reformed slowly, gaining average strength only in mid-March
- LS vortex remained very weak throughout winter
- Final warming was very late, in early May – characteristic after prolonged midwinter warming [e.g., Manney et al, 2005, JGR]
- ACE sampled both inside and outside the vortex (or its remnants) on most days
- MLS tracers show good agreement with vortex evolution reflected in PV contours

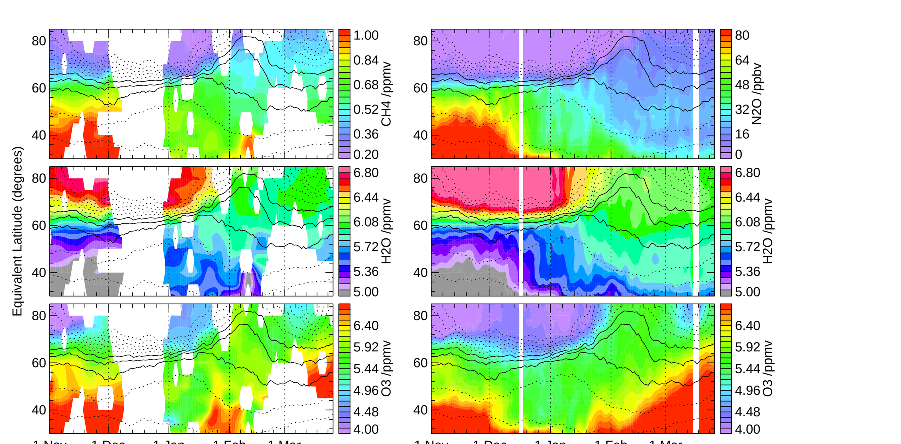
This poster summarizes large-scale transport throughout the stratosphere during the 2005-2006 winter, focusing on Aura MLS (Version 1.5) and ACE-FTS (Version 2.2, hereinafter "ACE") long-lived trace gas data:

- Equivalent latitude (EqL, the latitude that would enclose the same area between it and the pole as a given PV contour) time series showing tracer/vortex time evolution
- Vortex-averaged time series showing signatures of descent and mixing
- Observations and trajectory calculations showing fine-scale transport
- Preliminary comparisons with a SLIMCAT chemical transport model (CTM) simulation
- Meteorological data are from GEOS-4 (NASA Global Modeling and Assimilation Office Goddard Earth Observing System V4.03); v1.1 GEOS-4 Derived Meteorological Product (DMP) files are used for ACE [see Manney et al poster, this session] and similar pre-calculated values for MLS

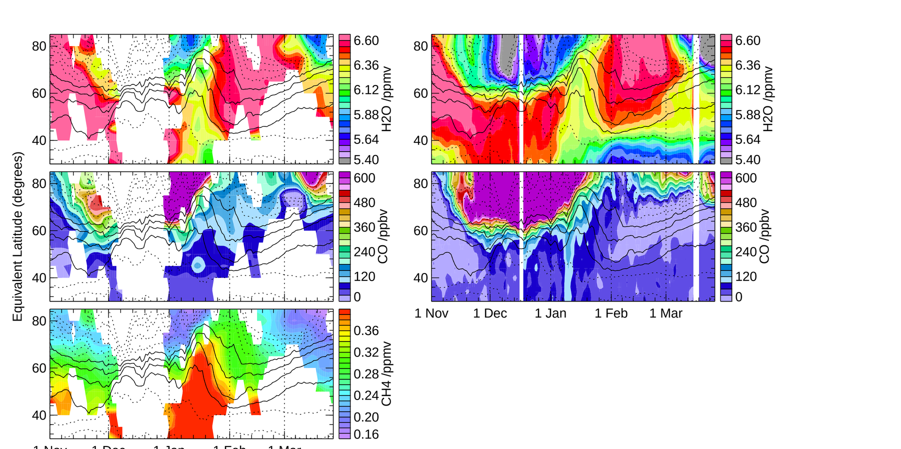
2 Time Evolution of MLS & ACE Tracers



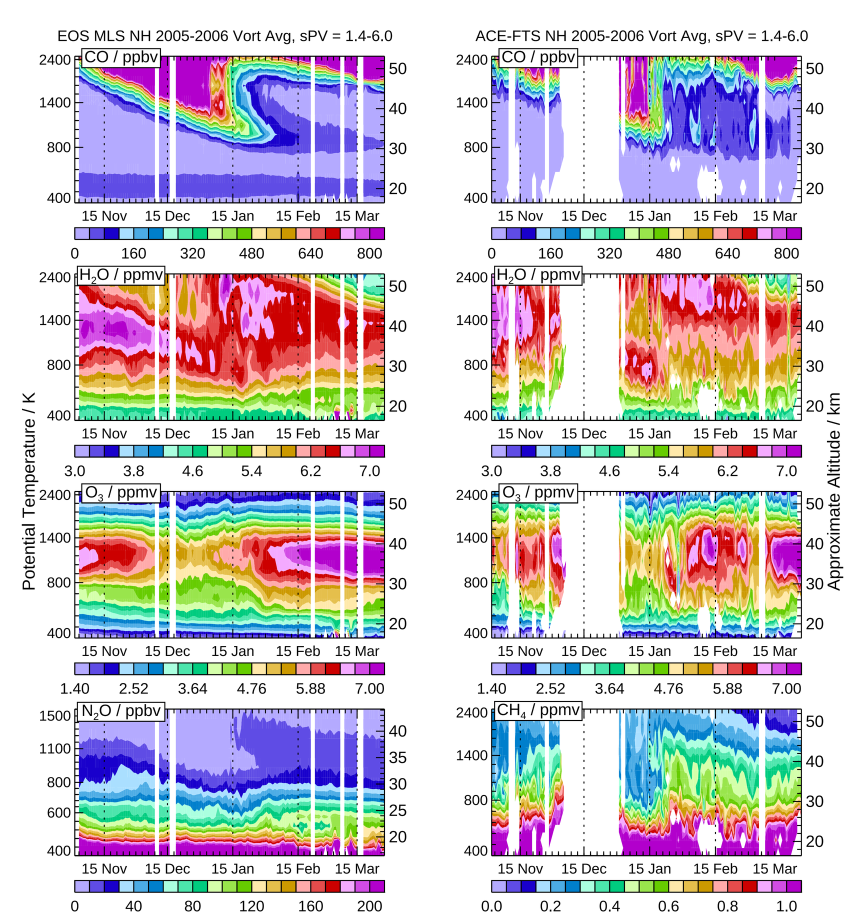
- Above EqL/time sections (top, ACE CH_4 and MLS N_2O; center, ACE and MLS H_2O, bottom, ACE and MLS O_3) at 490 K (∼19 km) show LS vortex breakdown in late January to mid-February; overlaid contours are PV, with solid lines in vortex edge region
- Small, weak vortex reforms by mid-March, then gradually shrinks and weakens again
- Brief decline in O_3 in January has been shown to be chemical loss in short cold period before SSW [WMO Arctic Ozone Bulletin, No 1/2006]
- Trace gases show extensive mixing out of vortex in February to early March
- Shrinking and near-disappearance of region of confined tracer values (low N_2O, CH_4, high H_2O) in vortex, followed by slight recovery



- Above EqL/time sections at 850 K (∼30 km) show MS vortex breakdown in mid-January to early February
- Much weaker vortex reforms by early March, then gradually shrinks and weakens again
- Tracer gases show mixing out of vortex and complete disappearance of signature (low CH_4, N_2O, O_3, high H_2O) of confined air in vortex



- Preceding EqL/time sections at 1700 K (top, ACE and MLS CO; center, ACE and MLS H_2O, bottom, ACE CH_4) show abrupt US vortex breakdown in mid-January
- Very large, strong vortex reforms by late February, resulting in confined region of high H_2O and CO, low CH_4; vortex then gradually shrinks and weakens
- CO decreases in spring via chemical processes, as sunlight returns to the polar regions [e.g., Solomon et al, 1985, JAS]
- Descent patterns during/after recovery echo those during fall vortex development; strong confined descent (decreasing H_2O and CH_4) continued into late April

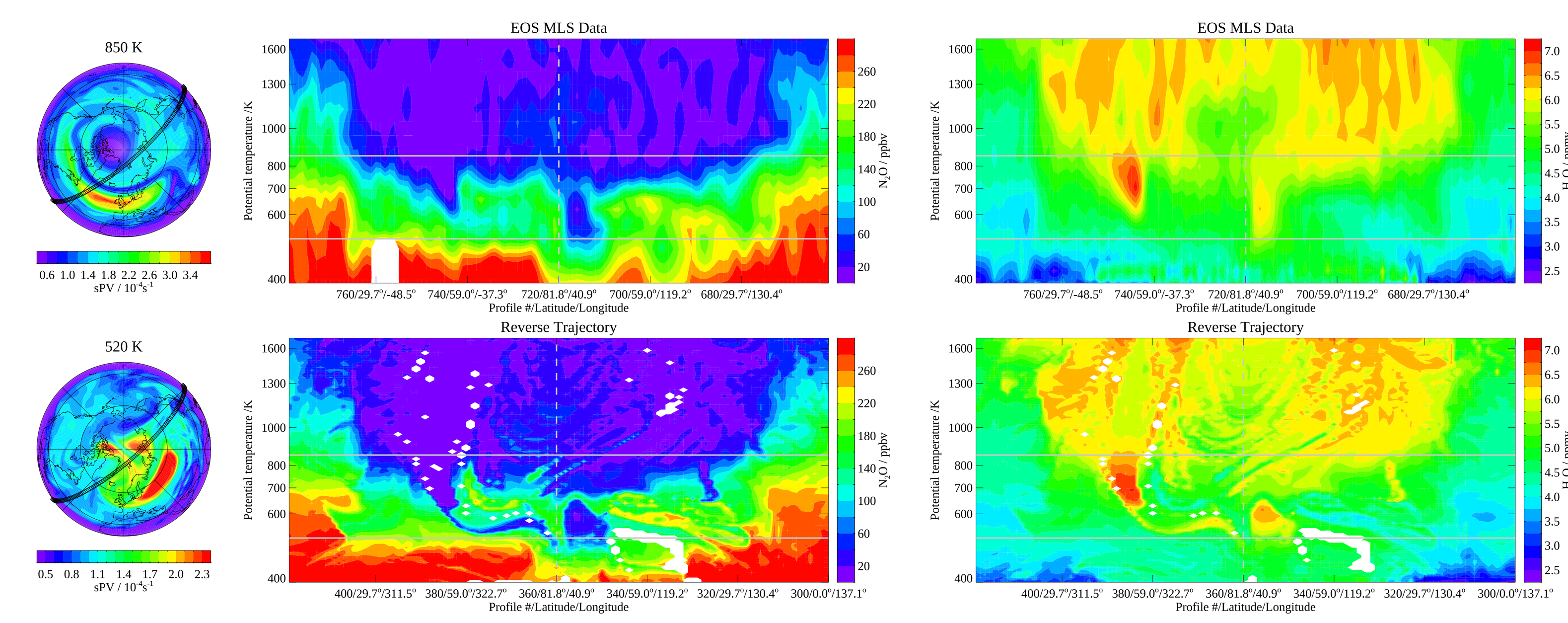


- Vortex-averages of MLS and ACE CO, H_2O, O_3 throughout stratosphere, MLS N_2O into upper stratosphere, and ACE CH_4 throughout stratosphere
- Signature of descent throughout stratosphere abruptly destroyed (by mid-January in US, mid-February in LS) as strong mixing brings in extra-vortex air
- Mixing signature particularly apparent in O_3 in MS (lower ACE values in late February/early March related to sampling effects)
- Descent signature reappears in MS and US by early/mid-February, with descending high CO, and low H_2O, N_2O and CO
- CO decrease in late March chemistry-related
- LS vortex remains very small/weak, with continual mixing, thus signature of descent does not reappear

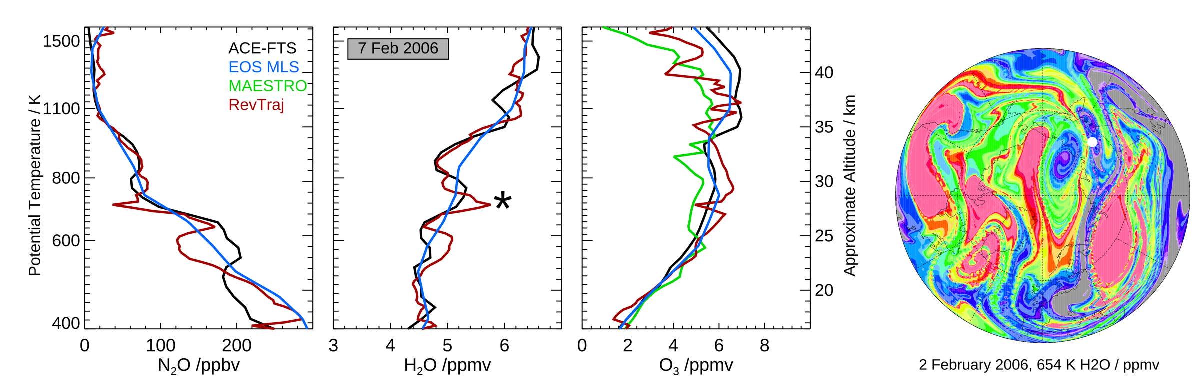
3 Fine-Scale Transport

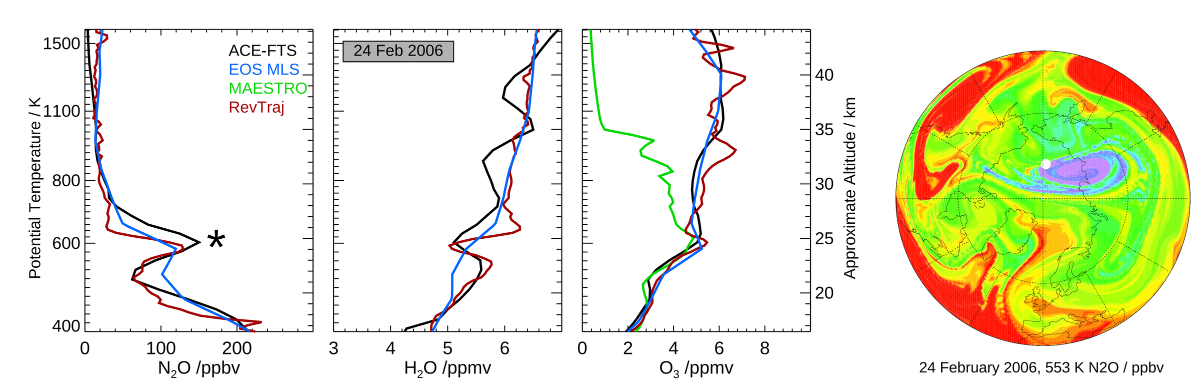
Extensive fine-scale structure developed during the 2006 SSW. High-resolution reverse trajectory (RT, aka "RDF") calculations are used to explore where and when ACE and MLS capture these features:

- Parcels started on the grid/at the time of the desired output (high-resolution map, profile, or curtain), and back trajectories run from these locations for 8–12 days
- Lat/lon gridded MLS fields (N_2O, H_2O, O_3, CO) interpolated to the ending back-trajectory times and locations
- These values, plotted at initial locations, represent a calculation of passively transported fields at the initial time/locations
- High-resolution profiles are at 100 levels equally spaced in log(θ) between 400 and 1700 K
- High-resolution isentropic maps are run on an equal area grid with 0.5×0.5° equatorial spacing
- "Curtains" for MLS are ensembles of profiles at each MLS measurement location along an orbit track

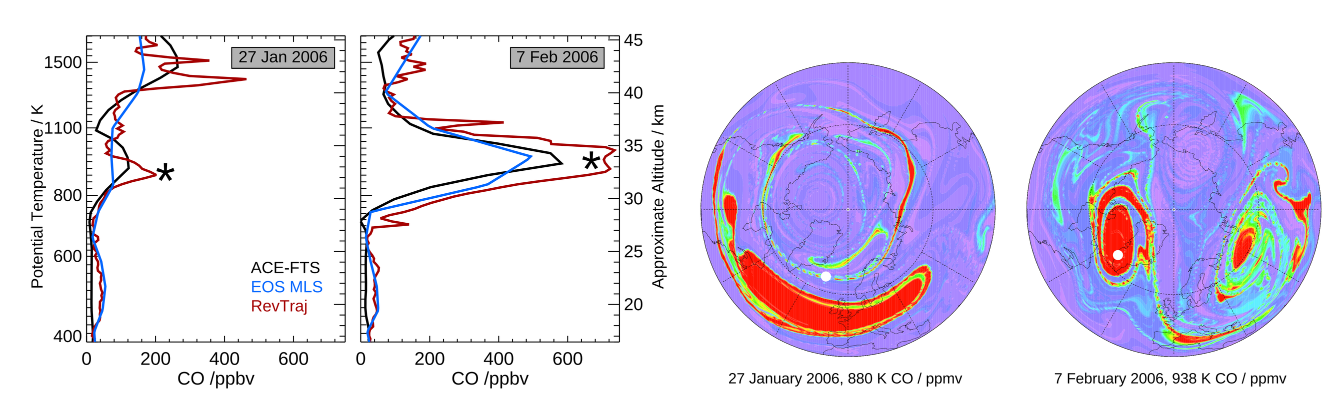


- Above figure shows 8-day curtains, initialized with MLS N_2O (left) and H_2O (right)
- GEOS-4 sPV maps (not RT) shown at levels of two horizontal lines on curtains, in middle (850 K) and lower (520 K) stratosphere
- Much of fine-scale structure reflected in MLS in "blurred" form despite relatively poor (3–4 km) vertical resolution





- 12-day calculations from ACE locations, initialized with MLS tracers (above); maps for level, species with * in profile plots; white circles shows profile locations
- MLS profile shown here is interpolated from gridded initialization field, thus may be smoothed compared to actual retrieved data
- ACE-FTS (2–3-km resolution at these levels/times), and MAESTRO (∼1-km resolution) appear to capture some small-scale features better than MLS, but all instruments show some features produced by filamentation/fine-scale transport



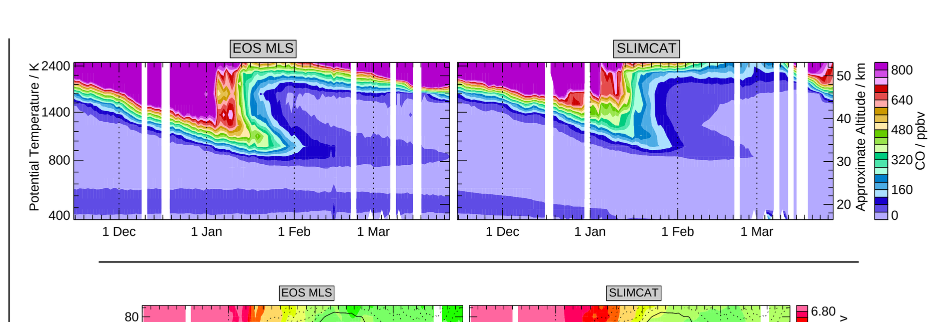
- 12-day RT calculations from ACE locations, initialized with MLS CO (above)
- Despite relatively noisy MLS CO measurement, fine-scale structure generated from this initialization can be seen in ACE data (27 January), verifying the reality of the structure in the MLS initialization field
- 7 February plot shows sampling within the vortex remnant over a narrow vertical range, captured well in MLS and ACE data

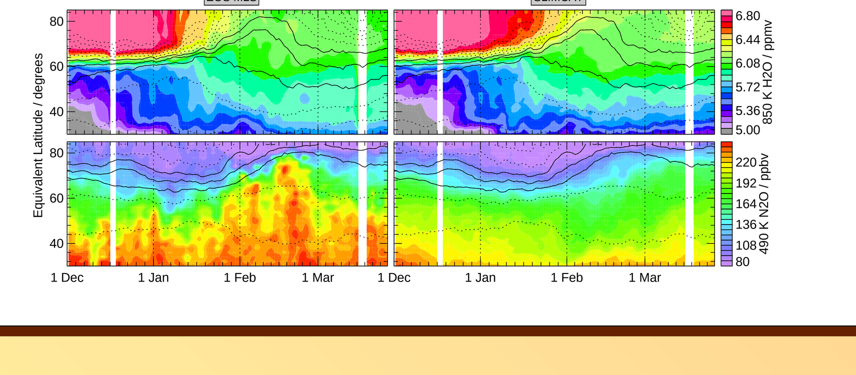
Thus, much of the fine-scale structure calculated to arise during the SSW is represented in the ACE and/or MLS observations

4 SLIMCAT Simulations

SLIMCAT simulations, sampled at MLS observations locations/times, for the 2005-2006 Arctic winter are being analyzed to help understand the transport processes:

- New version [Chipperfield, 2006, QJRMS] includes updated radiation scheme and hybrid σ-θ vertical coordinate
- Driven with ECMWF horizontal winds and temperatures
- Horizontal resolution 2.8×2.8°, 50 vertical levels from surface to 3000 K
- Initialized with MLS O_3, H_2O, HNO_3, N_2O and smoothed CO; other species taken from lower resolution multi-annual run





- First figure shows MLS and SLIMCAT vortex averaged CO
- Second figure shows MLS and SLIMCAT tracers as a function of EqL and time in the middle (850 K H_2O) and lower (490 K N_2O) stratosphere

These first preliminary comparisons indicate good overall agreement between MLS and SLIMCAT

- Assessment of differences (e.g., less CO "recovery" in model US, apparently stronger descent in model in LS) will further understanding of modeling transport processes using assimilated winds
- Further study of SLIMCAT results will help detail the transport processes taking place during the SSW

5 Summary

Transport during the January/February 2006 major stratospheric sudden warming (SSW) is being studied using the unprecedented wealth of trace gas data from Aura MLS and ACE. The vortex broke up in the upper stratosphere by mid-January, in the middle stratosphere in mid-January to early February, and in the lower stratosphere in late January to mid-February; this was one of the most complete vortex breakups seen during a major warming. MLS and ACE trace gases show strong mixing out of the vortex during the SSW, with the signature of confined descent disappearing or nearly disappearing throughout the stratosphere. After the breakup, the upper stratospheric vortex recovered very quickly, becoming unusually strong by mid-February; descent of trace gases in the vortex during recovery echoed that during fall vortex development. In the middle stratosphere, the vortex recovered slowly, remaining small and gaining average strength only in mid- to late March. In the lower stratosphere, the vortex remained unprecedentedly weak and permeable for the remainder of the winter, and there was little confinement of trace gases.

Small-scale structure that developed during the warming due to filamentation and fine-scale transport is explored using high-resolution trajectory calculations. Despite relatively coarse resolution, MLS and ACE both show evidence of much of the fine-scale structure suggested in the calculations.

Initial comparisons with SLIMCAT chemical transport model results show very good overall agreement; more detailed comparisons and study of the simulations will help to further understand and document transport processes during the major stratospheric sudden warming in 2006.